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Exploring Alternative Non-contact temperature measurements for ^{99}Mo production facility

NorthStar FY14 Activity 5, Deliverable 2

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Introduction

We have conducted an experiment to explore an alternative non-contact method of measuring the Inconel target window temperature. This experiment involves using a standard color camera to observe the visible light emitted from the Inconel target window at high heat in order to estimate the window temperature. The safety limit to prevent target window failure is 700 °C and therefore we need a reliable and accurate method of measuring temperature especially in the range of 600 °C to 700 °C if it is to replace the IR camera. In this temperature range the window will emit a significant amount of black body radiation within the visible range and hence the idea of using a color camera. The goal is to see if the shift in window color (determined by the RBG pixel values of the camera) as the target window is heated to 700 °C can be calibrated to the temperature. The reasons for exploring this as an alternative to an IR are camera are:

1) Significant cost reduction: The MTBF of our current model of IR camera (FLIR A650sc) is 20,000 hours which means these cameras will have to be replaced periodically on all beam lines at an approximate cost of $25k to $30k. A color ccd camera costs range is $1k to $2k.
2) Potentially less complicated to calibrate: The target window is a low emissivity metal surface, which makes measuring the temperature with an IR camera more demanding. The measurement of the emissivity must be conducted very carefully in order to mitigate the risk severely under reporting the actual window temperature. Calibrating the color of the target window, determined by the RBG pixel values, would potentially be a simpler process.

Test Setup

We used the same vacuum test chamber and target window coupon that we use to calibrate the IR camera as shown in Fig. 1. We removed the mockup beam line and place a quartz window on the 8 inch flange for a direct view of the coupon. A Canon Rebel XT DSLR model #DS126071 still photo camera was used to capture images of the coupons at various temperatures ranging from 600 °C to 720 °C. The camera was mounted to a tripod and focused to the target window surface through the quartz window and images were taken at ~ °15C intervals. An example of one of the images is shown in Fig. 2.

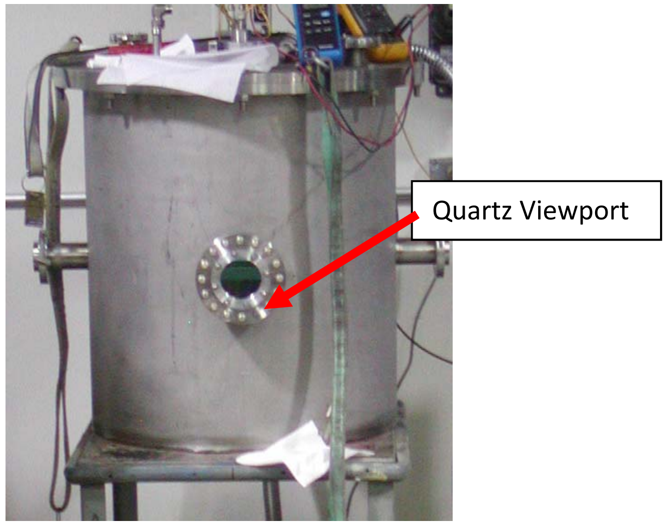

Figure 1: Vacuum test chamber with a quartz window on the viewport.

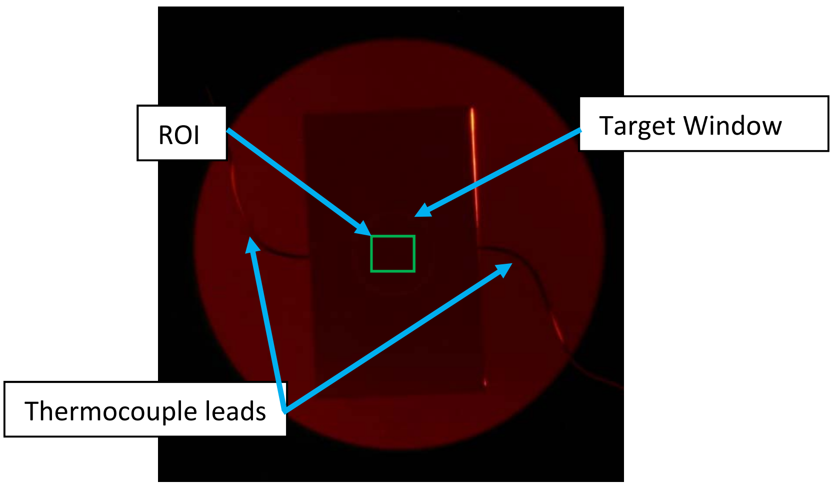

Figure 2: Image of the coupon at 716 °C

To calibrate the color images to the actual temperature we inserted two thermocouples into the target window coupon in the same manner done when measuring emissivity with the IR camera. The thermocouple leads can be seen in the image in Fig. 2.

Data Analysis

At the time each image was taken the temperature reported by the thermocouples was recorded. Each JPEG image was imported into a LabVIEW program developed for this test. In Labview a square region of interest (ROI) was drawn within the target window where we extracted the RBG pixel values and stored them into a 2D array. The location of the ROI is shown in Fig. 2. Table 1 shows the average pixel value for each color over the ROI along with the recorded temperature. The left side of the table is a portion of the image within the ROI.

Temperature	Red	Green	Blue
716	46.24	0.17	0
706	38.53	0.21	0
695	26.71	0.71	0
680	19.9	0.98	0
665	13.44	0.71	0
650	8.96	1.05	0
635	5.22	1.46	0
620	2.34	1.36	0
610	1.54	1.10	0.12

Table 1: Average pixel value for each color within the ROI and the recorded temperature for each image.

As expected from Plank's Law of black body radiation the red pixel values have the largest response as the temperature increases. The red pixel values vs. the temperature are shown in the plot in Fig. 3.The results show that red values increases approximately quadratically with temperature. This change is also visible in the images on the left side of Table 1 as the color of the image shifts from deep to bright red. Conceivably we use the red pixel response alone to measure temperature in the critical 600 to 700 ^{o}C range with proper calibration.

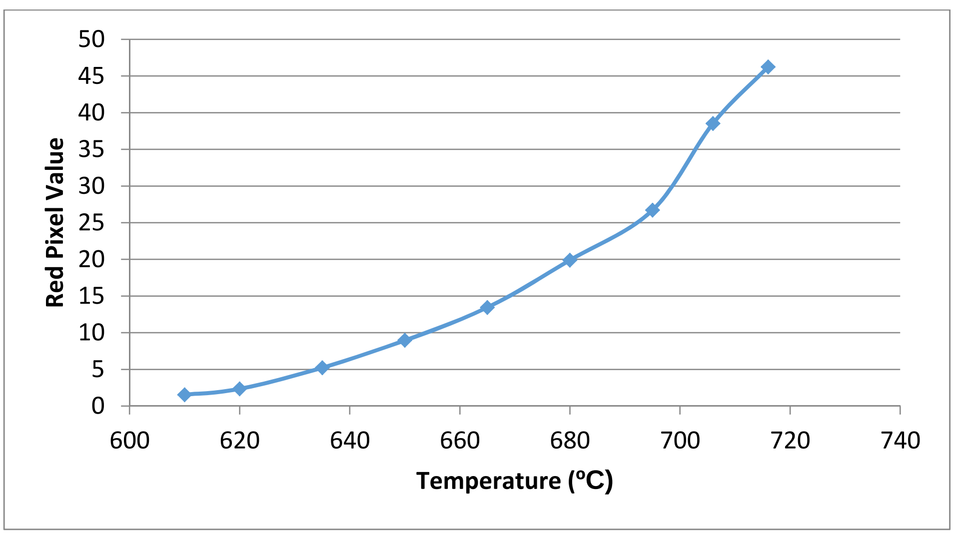

Figure 3: Red pixel values vs temperature

The response of the green pixel is also interesting. We expected the green pixel values to increase with increasing temperature however we observed a decrease. To understand this response we will have to conduct more tests. However, if the green pixel response is consistent or similar in other cameras and not an artifact of this particular camera then it opens another possibility for temperature measurement. Fig. 4 is a log plot of the ratio the red and the green pixel values vs. temperature. What we see is that the ratio of these pixel values is very sensitive to temperature, which makes it more accurate than measuring temperature with just the red values alone. Also, since it is the ratio that we are measuring, changes in the intensity of the light due to optical losses etc. will not affect the temperature measurement as long as any attenuation is constant vs. wavelength. In contrast, an optical loss not accounted for will reduce the accuracy of an IR camera temperature measurement.

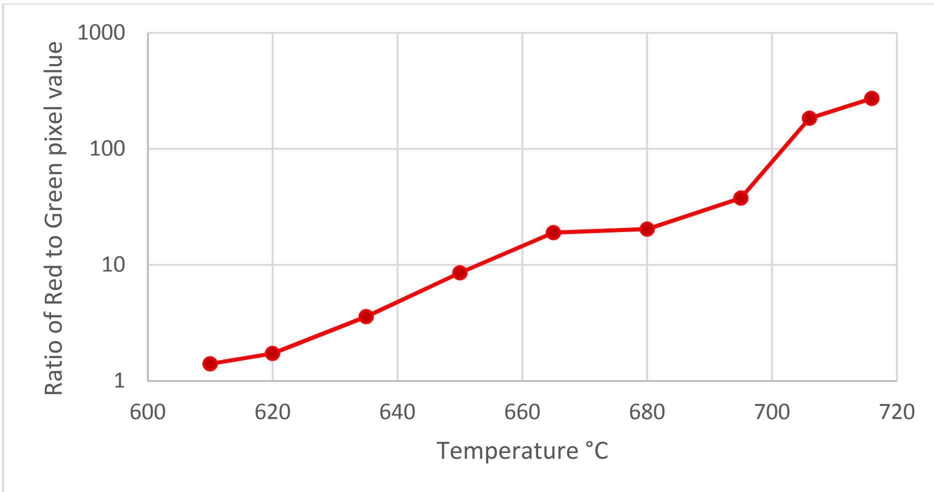

Figure 4: Ratio of the red pixel values vs temperature

Conclusions

From this preliminary test we have shown that there is potential for measuring high temperatures in the region of target window failure using a simple color CCD camera. One possibility of using such a camera would be to calibrate the red pixels values to the temperature. The other is the use the ratio of the different color's pixel values vs temperature. We believe these results show that these two methods are worthy of further development. In particular we would like to conduct further tests to better understand the decrease in the green pixels values with temperature. To do this we would purchase CCD video camera where we would have access to the spectral response of the Bayer filter (RBG filter) used on the CCD. We could then compare pixel response with calculated spectral intensity vs temperature (Planck distribution). If we would succeed at developing a method to measure temperature using the ratio of color pixel values it would be superior to IR methods for the following two reasons: 1) The color camera method would be immune to slight variations in optical alignment of mirrors that cause a loss of intensity 2) The cost to implement the color camera solutions would be substantially less than the current IR camera method.